

# Naval Enterprise Engineering: Design, Innovate and Train (NEEDIT)

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*Every generation of government Naval Engineers has a responsibility to see that the lessons learned and body of knowledge associated with fielded Naval equipment, systems and processes makes it to the next generation. Part of this knowledge includes the design methods and production techniques associated with producing the equipment. The transfer of design knowledge traditionally occurs over a long period of time through a design engineering internship. However, in recent years, acquisition reform philosophies involving a shift in design and production work to private industry have reduced the ability of this transfer to occur. The focus of the current naval engineering workforce is acquisition support rather than design of naval systems and equipment. This focus limits the ability of government engineers to develop the level of design expertise necessary for design innovation to occur as rapidly or as widely as in past generations. Leadership places a high priority on an innovative workforce, but an innovative workforce can only exist when the working environment provides workers with the opportunity to develop the appropriate expertise. Given the current focus on acquisition, the workforce of the future will most likely consist of innovative acquisition experts who lack the expertise to be innovative designers. This paper examines current naval engineering workforce development and in particular the changes brought about by acquisition reform to the area of design engineering. It includes a discussion of recent publications addressing building a design engineering workforce. The discussion reveals a possible pathway for creating more innovative design engineers in the future and builds a case for providing structured design engineer training. The paper also includes a description of a tool for providing an e-learning simulation based training program to help Naval engineers develop the necessary expertise in design engineering.*

## Introduction

It is very difficult to find a strategic planning document in the Navy or Department of Defense (DoD) that does not mention design as core capability. Within Naval Sea Systems Command (NAVSEA) for example, the strategic business plan states “NAVSEA personnel design, build, deliver and maintain the ships and systems of the greatest Navy in the world.” (Naval Sea Systems Command 2013-2018). Similarly, innovation has become a mantra for the scientific and engineering endeavors of many DoD organizations. DoD has long had a policy to invest in human capital as a strategic corporate asset as it assists in achieving performance objectives and the DoD Mission (Secretary of Defense 2013). The Secretary of Defense has further indicated that efforts must be taken to maximize the return on investment of “in-house” technical capabilities and facilities, specifically for technical work that would improve the Department’s technical product and cost knowledge (Assistant Secretary of the Navy (Research, Development and Acquisition) 2012). An example is NAVSEA’s policies identifying commitment to building the skills and competencies of its workforce in the most productive and efficient manner to support the Command’s mission (Naval Sea Systems Command 2005). NAVSEA’s training and development objectives include establishing a continuous learning environment in which employees: 1) Meet Command mission requirements, 2) Perform optimally at full-performance level and meet applicable certification requirements; and 3) Achieve career growth whenever possible.

Despite the stated focus on training in formal instructions, and the obvious correlation between naval engineering design competency and NAVSEA’s mission, there is very little training available for naval

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engineers relevant to developing the design engineering skill set in the civilian engineering workforce. There is no known government structured progressive long-term career training program that has as its goal the transfer the engineering design and production knowledge about equipment, systems, processes and design techniques to the next generation of civilian Naval design engineers. There is no formal ‘metric for’ or ‘certification of’ design skill level, competency, or tracking of the human resource. Yet, the skill set is recognized, as evidenced by the ship design workforce metrics from the NAVSEA Ship Design Manager and Ship Design Integrator Guide (NAVSEASYS COM 2012). Also missing is a structured pathway that might promote Naval engineering design innovativeness or develop the specific skills and expertise which might lead to design innovation in the civilian workforce. Instead, the training focus is on acquisition support and certification to meet Command mission requirements for Defense Acquisition Workforce Improvement Act (DAWIA) compliance. Efforts for some technical training such as the NAVSEA Engineer in Training (EIT) program have been terminated (Rickets 2011). Effects of the lost capability are potentially disastrous because they are very gradual, occurring over years as the design skills of trained active engineering workforce members slowly atrophy and leave the government as workers retire. So for the time being, the U.S. Navy is still the strongest in the world with the best equipment and most talented design innovators in the country on its team. However, recovery from the gradual loss of technical skills and corresponding ability to train the next generation will also be very slow, particularly if we do not capture the design lessons learned and transfer the knowledge from those capable of training design engineers before they retire. The ramifications of downsizing the engineering talent pool include longer project delivery times as engineering work is distributed among fewer resources, increased dependency on contracted engineering skills, and a decrease in the ability to realize and integrate innovative technical solutions. Consequently our nation’s Naval technological edge is at risk unless a program is created that transfers today’s production knowledge and design skills for naval systems and equipment to the next generation of civilian Naval Engineers.

This paper explores the current need and relevance of the design engineering skill set in the Navy and creates a case for considering the technical skill set, and in particular design engineering skills, as mission imperative to both support the acquisition process and to create an atmosphere of design innovativeness in the civilian engineering workforce of tomorrow. The journey will start with a quick review of specific technical skills and knowledge that need to be transferred to the next generation of Naval Engineers. Part of this exploration will include how such skills are currently being taught and identification of what has changed to reduce the effectiveness of old methods. A new method is then suggested for tracking the development of Naval design engineering resources by using a technique similar to how educators consider engineer student development in the academic world. The need for developing specialized design engineer training is supported by a discussion about current research into design thinking as a unique thought process. A link between design engineering skills and the overall design innovativeness of the Naval engineering workforce is then presented to show relevance to DoD’s current quest for innovation. The issues are then framed in a case made supporting the position that DoD has a need to provide a program that offers additional structured technical training to Naval engineers to fill current and future gaps in expertise development. A partial solution is then offered in the form of a potential interactive e-learning tool for Naval Design Engineers using applied problem solving techniques and a tiered on-line mentoring process for helping senior design engineers train new design engineers. Although it will never replace supervised practice, use of this tool would assist in a smooth transfer of Naval design engineering techniques and lessons learned. The over-arching goal of this paper is to

identify the loss in design engineering capability and then provide Naval engineering leadership a compelling case for structured Naval design engineer training that can be used as the basis for justifying the cost of a program. The hope is that the case will compel DoD to take the same bold and decisive action taken for acquisition reform to support the technical community.

## **Background**

Despite the fact that the United States Navy is the best equipped Navy in the world, the Navy is very aware of the problems associated with lack of technical training for the civilian engineering workforce that supports them. Experts have identified a steady erosion in the domain knowledge within the Department of the Navy over the past several decades, resulting in an over reliance on contractors in the performance of core in-house functions (Ricketts 2011). Acquisition reform is generally traced back to a DoD memorandum by Then Secretary of Defense William Perry. Along with the memo was a paper describing his vision for DoD Acquisition practices that should change to adapt to global threat changes and the new pace of technology development (Secretary of Defence 1994). The memo called for a bold and decisive change in DoD acquisition policy. In addition to the adaptive changes called for by this memorandum, one of the goals was to preserve defense unique core capabilities. Core capabilities such as designing, delivering and maintaining a Naval fleet require a well-organized and well trained technical team. The memo accomplished sweeping changes to acquisition policy and led to the growth of the Defense Acquisition University (DAU). However, the memo may have led to some undesirable losses in DoD technical capability. Acquisition reform has grown since 1994 into a paradigm shift from a ‘design and build’ culture to a ‘specify and acquire’ culture, partially by direction and partially out of financial necessity. The case presented in this paper is intended to provide feedback to DoD suggesting a course correction as a result of this loss in capability.

Part of the acquisition reform movement has included a general downsizing of centralized DoD technical staff. According to the General Accountability Office, “DoD performed downsizing during the period from 1989-2002 without proactively shaping the civilian workforce to ensure that it had specific skills and competencies needed to accomplish future DoD missions (Government Accountability Office 2004). In particular, NAVSEA underwent a substantial restructuring, or right sizing, in the 90’s that reduced the amount of “in house” technical engineering personnel and also shifted the majority of technical expertise to the Naval Warfare Centers. To put this in perspective, in the mid 80’s, NAVSEA 05 had 1500 personnel and as of 2007 the number had dropped to 265 (Ricketts 2011). In addition to decentralized to Warfare Centers, a lot of technical talent was lost during these reductions. Concurrently, a change in acquisition strategy trend from ‘design in house’ to ‘procure commercially’ changed the training emphasis of new technical workers, causing a reduction without replacement of design engineering talent. The acquisition strategy change and loss in design engineering talent applies to both hardware and software. Naval cyber systems is a rapidly growing area and the competition for talent in this area is extremely competitive with private industry because of the skill set’s breadth of applicability. In a 2007 speech, a former SECNAV stated that one of the biggest challenges faced by the Navy is finding the best ways to integrate design and production technology into an acquisition process that industry can execute (Secretary of the Navy Dr. Donald C. Winter 2007). Design in particular is considered the starting process for delivering a new Naval Warfare capability to the fleet (Tibbits 1995). The need to re-build and develop a steady pipeline of naval engineers is identified as being critical to the development of a robust engineering enterprise (Transportation Research Board of the National Academies 2011). A loss

in the design engineering capability represents a diminished defense unique core capability and is an indication that acquisition reform may have overshot Secretary Perry's intended mark. It is imperative that government subject matter experts have the opportunity to practice and stay involved in design/development/integration and engineering efforts to maintain continuity in all engineering fields within the Navy.

### **Definition of Key Terms**

One of the factors complicating communication of this issue and general understanding of the loss in design and production skills is evolving key terms. Specifically, terms like systems engineering, design engineering, naval engineering, and mentoring are in this category. Definitions and relevance to design, innovation and training issues are provided in Appendix A.

### **Characterization of the Current Government Naval Engineering Workforce Development**

As in prior years, new engineers bring fresh academic knowledge, new computer skills and creative thoughts when they walk into a new job as a civilian engineer for the navy. Beginning a Naval engineering career marks the start of a life-long pursuit of relevant knowledge about the equipment, systems and processes, and the material reality for applying their academic engineering skill set. A review of the engineering demographic within the Navy will quickly reveal that the percentage of engineers entering the civilian workforce with a Naval engineering background is very small (Galway 2010). A much higher percentage enter the workforce with a more traditional engineering background and then learn the Naval aspects of the job while applying the skill sets of their particular discipline. After entering the Naval Civilian workforce and completing the initial "on-boarding" processes and programs, engineers must acquire the relevant body of existing engineering knowledge about equipment, systems and processes necessary to become functional Naval Engineers. There are few elite internships and local opportunities for cross-training, such as the acquisition internship program, the Commander's Development program, and the Naval Surface Warfare Center's Center for Innovation and Ship Design (CISD), but the focus of this paper will be on the lack of opportunities and experiences available to the general population of civilian engineers interested in design and production.

Knowledge collection and assimilation continues throughout the duration of an engineering career. The balance depends on specific work assignments, skills, capabilities, and interests. A thorough engineering understanding includes knowledge of the relationships between the materials, technologies and practices associated with production and operations of Naval equipment through its life cycle. This understanding can best be gained by opportunities for supervised design engineering practice in these areas, but opportunities for this type of experience are limited and diminishing within the government. In particular, the opportunity to learn design and production related engineering skills is being replaced by acquisition support skills that focus on contractor oversight. In addition to needing design and production expertise within the government to maintain naval enterprise autonomy, the skill set is also needed to develop the ability to technically represent the interests of the government in contract negotiations, provide accurate production estimates, and conduct meaningful design reviews. SECNAV'S call for use of "In House" capabilities sets the tone for the expected continual financial contraction in DoD, and underscores the need for in-house technical resources to be fully trained and capable of performing tasks now accomplished by contractors in order to maintain continuity in key engineering areas. An engineering workforce with expertise developed to the level of being able to synthesize and analyze designs is also an

important risk management tool. DoD's risk management policy described in Mil-Std-882 identifies reducing risks through design selection, design alteration, and incorporating risk reducing features as the chief risk reducing strategies (Defense, Department of 2012). Consequently, successful acquisition programs are indirectly dependent on the design and production expertise in the engineering workforce.

The new generation of government Naval Engineers needs to understand and build on design lessons learned. The learning process being discussed here is not just a reading and memorization of facts and figures. The learning process is a transitional learning process where lessons learned in the academic world are slowly transferred and applied to situations, problems, and processes currently used by the Navy. This includes awareness and understanding of large amounts of information related to existing equipment, systems and procedures, and most importantly, how the engineering decisions made by prior generations have evolved from first principles to their present form as equipment and systems aboard Naval platforms. Because of the uniqueness of the environment and mission of Naval combat systems and equipment, the development of relevant Naval engineering expertise is something that is a mostly post-academic learning experience for engineers. Naval surface combatant ship design is a skill set unique to the Navy with design criteria very different from civilian ship design (Rickets 2011). However, apart from random discovery or personal investigation, the transfer rate of this body of knowledge is primarily influenced by on-the-job (OJT) experiences. An argument supporting the case for a formal training system is that the rate of transfer might be increased by organizing and prioritizing the generally applicable relevant information in a structured training experience. A second argument is that increasing an engineer's depth of understanding of general naval engineering principles and concepts early in their career will exponentially improve their ability to relate new information to existing practices and equipment. Training that improves technical background knowledge by providing reasoning for design choices, limitations and boundaries for existing systems, and requirement mapping to mission objectives is particularly relevant. Training should include an explanation of why the current system represents the best solution to customer needs in terms of affordable mission effectiveness. Ideally, engineers should be able to achieve a level of technical expertise that permits effective determination of when the cost is no longer worth the performance benefit, thus exploiting the "knee in the curve" outlined in the NAVSEA technical excellence and judiciousness pillar (Naval Sea Systems Command 2013-2018). Engineers must understand these questions and how to balance the associated engineering decisions with the severity and consequence of vulnerabilities and risks, as well as the probability of their occurrence, to continue the evolution of naval engineering technology. For Naval design engineers, this awareness needs to further include an understanding of underlying first engineering principles in existing design choices about material selection, fabrication, production, testing, and in-service engineering requirements. Without this understanding, future generations of naval civilian workforce engineers will lose the benefit of lessons learned by preceding generations and there will be a loss of continuity in Naval design expertise.

There is a real need for producing engineers with the resource awareness and the design judgment skills essential for creating a flexible design workforce capable of rapidly adapting to the changes destined to be part of the Navy's future. Part of the recent evolution of Naval Technology has included more complex and more deeply integrated systems and equipment, often multi-purpose and dependent on other systems (such as digital communications, mechatronic equipment, and specialized sensors). The more complex and integrated the material, the more important it is to understand past engineering judgments made in the design, selection and integration decision making process. Complexity of this sort also creates a need to professionally communicate with designers and experts from other disciplines and to look at the system

holistically rather than a disaggregated piece-by-piece basis. Fortunately some of this information is codified in specifications, guidebooks, and design histories. Drawings, technical manuals, vendor catalogs, test documents, selected record documents and engineering calculations, when available, are also very valuable forms of design philosophy communication from the original designer to engineers following in their footsteps. New engineers need time to be able to become aware of these data sources, understand their relevance, and use them to build from with new and more complex challenges. Accelerating this process with structured learning and reducing the time spent researching with a technical knowledge management system can facilitate development of technical expertise. One answer might be a DAU style training and knowledge management program (Galway 2010) or the design training method presented later in this paper. There is a real need for transfer of this knowledge by any method the Navy deems cost effective to maintain Naval design expertise continuity at all times.

### **A change in Acquisition Philosophy**

The good news is that we have the strongest Navy in the world and we are somewhat able to stand on the shoulders of giants in Naval Engineering and inherit baseline designs that, in most cases, represent a very mature product design. This good news is however tempered by the unfortunate reality that this fleet is aging and modernization efforts struggle to keep pace with technology. Another unfortunate reality is that the level of design history and government control over designs and design procedures has been reduced since the mid 90's by an acquisition reform effort that favors commercial products, less specification, reduced engineering support package detail, and in general less government technical involvement. Although the original intent of the acquisition reform was to reduce needless regulation and documentation, the cost reduction seductiveness of going beyond this initial intent in a contracting government budget environment entices programs into accepting high levels of latent technical risk by not purchasing or producing the same level of engineering information that might have been bought or produced in past acquisition efforts. Arguably, a highly trained and experienced design engineer might be able to make cuts in some areas and show some program savings. However, there are apparently not many of these seasoned veteran design engineers involved in acquisition strategy development, and no training ground to develop the next generation of these decision makers. The frustration with this strategy is that acquisition support engineers without design and production engineering skills will have no basis for identifying, assessing, and justifying the most cost-effective balance of design related technical risk management measures early enough in the acquisition process for them to be effectively implemented. An example would be enough awareness of the long-term benefit of specific engineering data package information needed to later modernize or upgrade key equipment and systems.

The engineering data package associated with every acquisition of complex equipment should contain sufficient quality and quantity of information to remove most of the risk of the unknown and minimize technical stakeholder risk acceptance. A contractor's 'burden of proof' is coupled to an associated degree of certitude in claims of adequacy relative to meeting requirements and conforming to constraints. The level of certainty must be of sufficient magnitude to achieve stakeholder acceptance that the claims are valid. Doerry notes that when funding becomes scarce, engineering, analysis, documentation, testing and government over-sight are reduced to help defray the costs. This in turn increases the risk that the technical issues will be discovered later and the corrective action will be expensive (Doerry 2009). This type of technical risk is latent and often goes undiscovered during the procurement phase only to surface later during modernization, repair, or modification of the equipment become necessary, well after the



procurement phase is completed. When discovery does occur, and the severity of the technical risk that must be managed comes to light, the technical authorities have few options but to accept the risk. Unfortunately, this may translate to additional risk acceptance by the Operational command or the end user. Also lost in decisions reducing engineering data are any collective benefits to future engineers this information might provide in the way of advancing the art of Naval Engineering or increasing the total body of Naval Engineering knowledge. In particular, the decision to minimize engineering data package level information and decentralized collecting of technical data packages has indirectly transferred decisions about its potential future engineering workforce support capability to individual program managers. These realities have offered some programs short term cost benefits, but have actually hurt the ability of the individual organizational business units to transfer design knowledge to the next generation of engineers, thus reducing unnecessary schedule and cost risk growth tension with programmatic authority personnel.

In addition to the swing in acquisition policy, down-sizing of the government technical workforce has made it imperative that consultants and contractors be hired to fill the drafting, design and engineering gaps. This policy shift has both removed many opportunities for government engineers to practice in design and production, and created a bigger engineering management role for government engineers involved in contractor over-sight. This role might explain the scope growth of DoD's definition of systems engineer and the emphasis on engineering management functions. The new role provides an increase in breath of responsibility, but precludes the level of immersion into design projects that is required to gain the fundamental understanding and foresight that a complex system architect or systems engineer might require to effectively balance systems across disciplines.

DoD has turned to the Defense Acquisition University (DAU) to teach the engineering workforce about the complex government acquisition process. Yet, the DAU specifically identifies that there are two domains, technical and engineering management associated with systems engineering, and that the DAU only provides training to engineers in the engineering management domain (Defense Acquisition University 2001). The technical discipline leadership in the organizational technical business units and technical authority support pyramids associated with each Naval Systems Command need a structured means of capturing, managing, and transferring technical knowledge with the same level of support that the DAU has given the engineering management discipline associated with acquisitions. Without such a means for handling the technical side of the equation, the systems engineering training focus is on perfecting the engineering management side of the acquisition process rather than providing well balanced technical and engineering management solutions to acquisition problems. By focusing only on half of the needed training (engineering management discipline), yet stressing the importance of skills such as design and production knowledge that are the result of the other half of the training (technical discipline), DAU has created a top down approach to engineering acquisition support that might leave the technical workforce feeling inadequate when called upon to answer production or design related questions. The significance is substantial relative to the aforementioned influence of design and production decisions in the acquisition process. Similarly, when advice in design and production is requested, it is often the result of some program crisis management action and pressurized by a need for accelerated learning and short fused decision time constraints. Program and project engineering management processes also tend to be very regimented and time based to meet production milestones and contractual deadlines. They align well with design development following a convergent linear thinking style progressing in small steps (serialist) (Cross 1998). Regimented management processes can however

create tension in design engineers employing more of a lateral (deBono 1970), divergent style, in which an over-arching and broad perspective of the problem (holist) (Cross 1998) is considered until converging eventually on a final solution. In fact, the iterative nature of many approaches follow the principle of least commitment, which only makes irreversible design decisions when absolutely necessary. This type of approach (such as Set-Based Design) maximizes design flexibility (Lamb 2003). However, it may add some risk to schedule or require program managers to trust that the design function is occurring as expected with little in-process verification, since concrete progress will be hard to track. This can create unnecessary project tension and an adversarial relationship between technical and programmatic sides of a program if the Program Manager (PM) lacks confidence in the government design team. A well trained design team with experience in many balanced design approaches should have the support and confidence of program leaders.

In a fiscal environment with limited training budgets, even a minimally funded mandate that emphasizes the needs of systems engineers to focus on the engineering management domain and get DAWIA certification at the expense of additional technical training is unbalanced. The result is an underfunded training requirement for the Navy in the area of developing technical systems engineering expertise. The technical skill sets most impacted by such a strategy are those taking the longest to develop, such as design engineering expertise. Since it is unlikely that acquisition policy will radically shift back to pre-acquisition reform times, there needs to be a plan to help transfer the knowledge required for continued Naval Engineering dominance to the next generation that does not completely depend on design immersion or opportunity to practice design engineering. In order to create the plan that enables the Navy to maintain control over the entire shipbuilding acquisition process, including the technical domain, an understanding of the impact of acquisition policy changes to technical engineering skills needs to be understood.

### **Ramifications of Acquisition policy shift on design skills**

There is a negatively synergistic effect to overall technical capability caused by the many small adjustments made by the Navy to comply with DoD's acquisition reform policies. Specifically, the subtle shift in the roles of engineering workforce members has caused some unintended consequences to the collective design and production skill resource pool. Little attention has been given to improving the rate or quality of new engineer technical development and there have been several factors that have negatively impacted the development of design engineers in the Navy in the past 25 years. A list of specific examples of recent changes are captured in Appendix B.

A few key points to note from Appendix B that make these losses of particular concern to acquisition support efforts. First, in order to be able to effectively provide government oversight and accurate cost estimating for contracting out design engineering in an acquisition program, the engineering workforce must have an understanding of what it entails, and be able to estimate the level of effort required for various projects and associated tasks. This sort of understanding is only gained by experience. Second, development of the design expertise required for design innovativeness requires immersion in the relevant processes and continued practice to remain cognizant of the skills and effort required. Design expertise includes the engineering decision making processes associated with applying knowledge to problem solving, artifact production, and system integration. Failure to achieve and retain the level of subject matter expertise required to be an innovative workforce member greatly reduces the ability to supply

relevant and realistic technical innovations on demand. Engineers without these skills will try and solve the problems with expertise they do possess. Consequently, if the only training government workforce engineers receive comes from DAU, then logically the initial solution attempt will involve engineering management process renovations or somehow capture the innovativeness of the contractor workforce through teaming. This can work in some cases, but the responsibility for naval technical innovation stewardship belongs collectively to government engineers, and there will be instances where contractual administrative inertia or other circumstances will prevent tapping the contractor resource for innovation. Similarly, stewardship of the human resource responsible for naval innovation belongs to the technical leaders and organizational supervisors making resource and training decisions for the fleet today. It is imperative the navy motivate, inspire and facilitate design and innovation in their technical workforce. This workforce needs to be concretely built, tracked and mentored, not left to the chance associated with OJT and contracted talent.

### **Training Engineers in Naval Engineering Design skills**

Design engineers are the front line innovators, effectively innovating on demand. Failing to provide the opportunity and training for this skill set to fully mature will deprive the Navy of the very skill needed to achieve the greatest degree of affordable mission operational effectiveness. A bad design will lead to poor results for the war fighter in service independent of the efficiency of the acquisition process. In terms of Naval Engineering, this involves creating a workforce that understands the equipment and systems of today as a means to get the knowledge needed to solve the problems of tomorrow. A Naval Engineer with this understanding is capable of cost effective design decision making, and with enthusiasm, curiosity and diligence can push the envelope for continued naval equipment superiority.

The tools, techniques and methods determined to be the best for improving design engineering and innovation need to be developed into usable learning modules for new design engineers within the Navy and administered by experienced senior design engineers. Chief among them are:

- basic naval design skills development,
- design thinking and creativity,
- design leadership, and
- design art propagation.

Basic design skills involve the application of knowledge of engineering, production processes, materials, and prior art and the ability to accomplish the work associated with design. Design creativity involves an ability to creatively solve design problems and synthesize design solutions, define the problems to solve, and forecast potential problems resulting from producing functional design products and associated design alternatives. Design leadership involves understanding design approaches and philosophies, applying them effectively to products, and making good design decisions in light of these approaches and philosophies. Examples of a design approach would be the design spiral or Set based design. A design philosophy is a weighted list of attributes used in the evaluation of alternatives (Lamb 2003). Design leadership also involves helping guide a well-balanced team to solutions that optimize affordable mission effectiveness goals. Design art propagation involves being aware of design data and objective technical evidence that will support key design alternative value judgments and engineering decisions, and archiving it in a manner that enables future in-service engineers to get what is needed to solve emergent problems. Continuity and propagating the art involves mentoring the next generation of design

engineers, looking for and taking advantage of teachable moments, and continually optimizing the methods and practices used to handle known design problems. These aspects of naval design engineering are things that need to come from experienced naval design engineers. Program managers and engineering managers without knowledge of or direct design experience will have a difficult time providing the environment, opportunities, and training plan that foster growth for design engineering skills. It is a skill set that requires direct experience to understand, develop and fully utilize. If the Navy recognizes this contribution and helps provide resourcing and structure to foster it, there is a chance that such efforts will be met with the professional goodwill, acceptance of informal mentoring responsibilities, and promulgation of the “can do” attitude within the design engineering community necessary for long-term success and role development.

A great deal of study has occurred in recent years in the area of design thinking and design intelligence that indicate designers might approach problems differently than other engineers or managers. Nigel Cross suggests that design ability is a multifaceted cognitive skill that involves ‘designerly ways’ of thinking and doing that set it apart from other skills (Cross, Design Thinking 2011). Cross suggests three key strategies for design thinking that involve taking a broad systems approach to the problem rather than accepting narrow problem criteria, framing the problem, and designing from first principles (Cross, Design Thinking 2011). He further suggests that designers tackle ill-defined problems; their mode of problem solving is ‘solutions focused’ and constructive (Cross, Designerly Ways of Knowing 2007). Appendix C provides a table of the core attributes of design thinking (Curedale 2013). The relevance of Cross’s work and Curedale’s table to the need for design engineer training is to illustrate the uniqueness of the Naval Engineering design skill set and support the argument that designing is different than other thought processes.

### **Engineering design dependency of New Ship Design techniques, strategies and philosophies**

The new techniques, strategies and philosophies used in ship design generally all require a high level of naval engineering design proficiency. Many recent ASNE articles about design have focused on complex over-arching ship design techniques or new quality control measures. These are outstanding efforts all targeting a continued push forward for the art of Naval engineering. However, one thing they share in common is a dependency on a design engineering workforce that efficiently and effectively delivers products created by these new plans and procedures. Extensive use of COTS products, Cost as an Independent Variable (CAIV) (Doerry 2009), Performance Based Design (Famme 2009) (Rickets 2011), Concurrent Engineering (Tibbits 1995), Designing for producability or supportability, Set Based Design (Singer 2009), and open ended architectures are all examples of techniques where design expertise from the workforce is a baseline assumption.

Perhaps the most prevalent strategy in DoD is the extensive use of COTS products. Use of COTS hardware and software demands a very high level of design engineering expertise to enable understanding of the over-arching vulnerabilities and risks when identifying them for new construction or integrating them in to existing platforms. It has been said that the art of shipbuilding lies in the ability to buy a wide variety of semi-processed and fully manufactured material and equipment from other companies and combine them efficiently in a finished ship. (Colton 2003, 3-20). NAVSEA has identified the use of COTS products as a “preferred strategy” (Naval Sea Systems Command 2000). Use of COTS products is not something new to the ship design world, but using them introduces complexities and new risks that

require special strategies, plans and budgets to handle initial integration design issues and latent life-cycle support issues. These risks and complexities demand extensive knowledge of “best practices” for development, modernization and maintenance related issues (Naval Sea Systems Command 2000). Consequently, when they are used in a larger piece of equipment, system, or system of systems, forecasting their performance and overall impacts to operational availability, reliability and maintainability requires advanced design knowledge in the areas of systems integration, installation and life-cycle effectiveness. Integrating commercial items can actually drive the architecture of the overall system architecture and design (Secretary of Defense 2006). One of the thoughts behind using COTS/NDI hardware and software is to design with open system architectures, using commercial interface standards. Designing for open system architectures involves design consideration for portability, interoperability, scalability, and ease of integration. Understanding the design implications of each of these concepts individually, and the design judgments associated with balancing them with other desired performance features and design constraints also requires advanced design capabilities and foresight. The pursuit is very difficult for trained design engineers with a high level of expertise and all the engineering information. One of the realities of using COTS is that commercial items rarely come with enough adequate technical data to enable extensive engineering analysis and review and often have proprietary interfaces. This makes the job of integrating them more difficult and involves higher risk, particularly for engineers having little or no design and production experience from which to extrapolate quality engineering judgment decisions.

Using CAIV as a methodology places a high demand on naval design engineering expertise. Specifically, CAIV is used to acquire affordable DoD systems by setting aggressive, but achievable life cycle cost objectives, managing achievement of these objectives by trading performance and schedule as necessary (Doerry 2009). This is a worthwhile goal, but requires design engineers that have been further trained to dissect, isolate and extract the cost of equipment, installation procedures, integration decisions, and the effects of other variables. An analysis of this kind demands understanding about the design, production, installation and supportability inter-relationships for complex systems and equipment, particularly for when preparing a reasonable cost estimate. In large or complex systems and equipment, there are layers of trade-offs, performance balances, packages of equipment, and multi-functional systems involved making this an exceptionally difficult pursuit to achieve any realistic results, once again requiring an advanced level of design and production expertise for reasonable application. A further complication for government engineers is the need to accomplish these tasks as a third party observer within the production communications limitations of a contract interface.

Designing and assessing supportability, designing for CAIV, using COTS/NDI equipment, and similar system design methods involve achieving a balance between technical effectiveness, process efficiency, and cost effectiveness as the program strives for the DAU concept of affordable mission effectiveness. Each of these concepts involves a roll-up of several design consideration attributes. DAU provides guidance as to the meaning of these concepts from an engineering management perspective, but understanding and communicating the impact of these attributes to a specific type of equipment or system and applying them to new designs or modification to existing designs of Naval equipment is a skill that takes years to learn, given ample opportunity to practice. Making affordable mission effectiveness a design requirement for Naval Enterprise Acquisitions is a worthwhile goal, but unless the civilian workforce is capable of successfully contracting or accomplishing this design work, the goal is little more than wishful thinking.

The demand for design engineering skills by these strategies, or any other, brings to the limelight the importance of design engineering human resource awareness. This awareness involves a level of expertise, relevant subject matter knowledge, experience, aptitude and several other factors. One of the bigger factors is opportunity to practice and be immersed in a design and production environment. There are not enough opportunities to achieve the expertise needed to promote widespread innovation in design among the general population of DoD and Naval engineers. This is exacerbated by the Navy contracting out much of this type of work. However, there are still places where these skills can be developed. Opportunities for production experience in the Navy occur at :

- Naval Shipyards
- SUPSHIP
- On-Site Rep at commercial production site
- Lab manufacturing facility

Opportunities for design experience in the Navy:

- Planning yards
- Warfare Centers
- Special focus teams
- Design research

Rotation with commercial yard would also help both in production and design experience (different than on site rep capacity-emphasis on doing not overseeing)

These activities represent opportunities for cultivating relevant naval design engineering expertise and growing an innovative design engineering workforce with production experience within the Naval community. Although the trend in current practice is to employ senior technicians as on-site representatives at commercial production sites, pairing a senior technician with junior engineers can be a tremendous learning opportunity when time and funding permit. An increase in potential developmental rotations involving some design work may help foster at least long-term design awareness if not expertise. Careful management of design engineering human resources and exploiting every potential learning opportunity or teachable moment from these activities is part of the path towards increasing Naval Enterprise Technical Innovation.

### **Methods of Increasing the potential for Technical Innovation**

It is imperative that the Navy be pro-active in new design engineer workforce development. Innovation is just a ‘buzz word’ unless there is a realizable path to achieve it. An innovative design engineering workforce needs to be developed, not left to the chance of on-the-job training alone. The filtration and transition of Naval knowledge and decision making processes relevant to design engineers to solving the problems of tomorrow should be monitored and controlled continually. There are many tools for innovation. McKesson suggests that innovation tools follow a shared structure, or morphology that involves problem definition, problem generalization, search for solutions, apply solutions, implement application, and learning (McKesson, Innovation in Ship Design 2013). Since the ASNE definition of Naval Engineering includes Naval Architecture, work done by McKesson to answer the question “What is innovation in Naval Architecture and can it be taught?” becomes directly applicable. McKesson offers the following answers to the question:

- Innovation is not the same as invention, in that it is focused on fielding a product
- Innovation is a subset of Design, which is a subset of Creativity
- Innovation requires expertise: there is a subtle connection between the Metaphysics of Innovation and the Metaphysics of quality
- Innovation requires specialized skills and aptitudes
- Innovation is facilitated by the use of certain tools
- The use of those tools does not guarantee innovation-tools don't make the artisan, they only help him/her
- The practice of using innovative tools can result in developing innovation skills.

So the question now becomes 'How do we increase the innovation associated with this overall Naval Engineering process?'. One method is to enhance the innovativeness of personnel associated with the various roles in the process. These roles include the initial design, analyzing and refining of the product, reviewing the product relative to lessons learned, and managing and coordinating the product through the development cycle. The roles are not well structured and the people in the roles are in a continual state of development relative to their design skill set while they function in the role.

Applying McKesson's relationship between creativity, design and innovation, a logical first step from an organizational perspective is hire intelligent and creative people. This may seem easy enough to do, but technical curriculums associated with the engineering disciplines are fairly structured and rigorous. For most, competition in engineering school is an academic pressure cooker and all efforts are put into scholastic performance. In this environment there are not a lot of opportunities for creativity. Still, in looking at extracurricular experiences, internships and design projects where an aptitude for design might be evident, there is some stratifying data beyond the grade point average that might be an indicator for design potential. Efforts taken to promote Science, Technology, Engineering and Math (STEM) early in education development might foster such creativity. Engineering managers might consider creative differences in building engineering design teams to strike a balance between breadth of variation in experience and knowledge, and depth of understanding in core areas. Once intelligent and creative people have been hired into an organization, the next step is to develop the expertise needed to make them good design engineers by enhancing the relevant creative skills.

McKesson identified expertise, specialized skills, and aptitude as elements required for innovation. Technical expertise and skills development can be taught. There is no guarantee for innovation if all these skills are developed, or requirement that these skills be in place for innovation to occur. Some might agree with Seneca, and suggest it happens when opportunity meets preparation. However, time has shown innovation is not truly random and that proceeding down this learning path is just following the logic Pasteur noted in his remark about chance favoring the prepared mind (Pasteur 1854). Arguably, by increasing the breadth of experience this may also improve creativity as well. It is noted that McKesson identified several other influences, such as knowledge of metaphysics of innovation and quality, and proficiency in structured innovation tools. Development of these skills in parallel would be dependent on student motivation and represent more advanced innovation development areas. The key point is that expertise and skills development are prerequisites for innovation to occur and their value might be applied to many other areas of a Naval Engineering career as well as design.

Professional development yielding relevant Naval engineering expertise sets the course for Naval Enterprise Innovation and professional engineer career development. In the current financial environment, there is a fixed and diminishing training budget, often with politically set priorities for the civilian workforce. The fraction of time available for technical training has reduced, while the requirements for non-technical training have increased, creating a squeeze on the time and resources available to develop an innovative technical workforce. Clearly an innovative workforce is on the 'want' list of all organizations within DoN, so how can we take steps to achieve the goal?

### **Applying Academic engineering metric analogy to Naval Engineering workforce development**

Actively developing a naval design engineering workforce requires some metric for measuring skill level and skill development. The transition from academic life to professional Naval Engineer working life involves some form of new learning experience, analogous to the transition from high school to college life at engineering school, but with a more focused subject matter and increased breadth of independent responsibilities. The similarities are substantial enough to consider using a metric developed by academic professionals for monitoring the development of engineering students as a model for a metric for Naval engineers transitioning into the workplace. In one metric, Oklahoma State University created an Engineering Taxonomy poster in a grant from the National Science Foundation for mapping the progress of students through the engineering curriculum based on Bloom's learning taxonomy (Cheville 2006). In this effort, a set of 9 abilities (facts, concepts, meta-cognition, research, decomposition, model, implement, measure, and communicate) were arranged as rows, and divided into four levels of mastery of understanding (understanding, applying, analyzing, and designing) serving as column headings. In each matrix block, the poster provided a stratified explanation of how a student might demonstrate a particular mastery of the level for that ability, along with several examples. The developers of this poster provided information in each matrix cell that enabled educators to quickly identify and classify general engineering knowledge. Individual cells enabled engineering knowledge organization by: "a) defining skills, abilities, and characteristics of students who exhibit this knowledge; b) listing questions representative of each type of knowledge, similar to what might be asked on an examination; and c) characteristics of student artifacts that would demonstrate competence" (Cheville 2006). If a similar taxonomy were used to assess the transition of engineering student into Naval Engineers, it would provide a metric for engineering managers to see where developing employees were on the path to becoming functional naval design engineers. Other advantages of such taxonomy include determining effective instruction methods, determining how well engineers are learning, and determining how to help engineers learn better (Andersen 2001). A side benefit is that it would provide junior engineers a means to understand development expectations and how leadership expected them to master engineering abilities relevant to design engineering. The Oklahoma State University effort was originally set up for electrical and computer engineers and while both of these disciplines make up the broad category of Naval Engineers, one area for additional research might be to further tailor this matrix to the specific needs of Naval Engineers in a professional workplace. An interesting observation from this effort relative to training innovative Naval Engineers is that designing (or creating from Bloom taxonomy) is the highest level of mastery of these abilities. This is significant in the Naval Engineering community, because the term designer or design engineer is usually thought of as a person or role in the production process rather than a level of mastery. A metric analogous to that prepared by Cheville tailored to Naval Engineering would



provide engineering managers and technical authority leadership a means to quantify the skill level and areas of competency of the design engineering resources within the Navy at all times.

### **Making the case for Naval Design Engineer training to DoD**

The case for training Naval design engineers begins with Naval leadership's recognition of the importance of design engineering in accomplishing the NAVSEA's mission and acknowledgment of diminishing expertise in this area in the current Navy. The shift in expertise from design and production skills to acquisition support skills has evolved with the continued implementation of DoD's policy for acquisition reform. There exists a knowledge management and training program for acquisition support, but no equivalent program for the technical skills development that parallels DAU. Specifically, there is no structured progressive technical or design training system in place within the Navy that transfers the body of knowledge associated with the design of existing equipment, systems, and processes to the next generation of engineers. The current primary method these skills are acquired is through OJT. The opportunities for OJT to acquire design and production skills through practice have been diminished by a number of factors, but chiefly a philosophy change and secondary by-products brought about by acquisition reform. Engineers being trained by DAU as systems engineers to provide acquisition support are provided training focused on engineering management rather than the technical skill set. Training Naval design engineers involves application of basic academic engineering tools and first principles to problems and requirements of Naval customers. Metrics exist for tracking development of engineers in school that might be modified for use in tracking development of Naval design engineers in the workplace. Development of design engineering judgment, foresight and eventually expertise requires the right environment and mentorship for success, as well as the opportunity to practice. There is evidence that designing involves a thought process and skill set that is different from other thought processes. Many of the current ship design strategies and methods presume a workforce with a high degree of design expertise as a prerequisite for success in building Naval ships and solving Naval problems. Current DoD initiatives seek innovation to help maintain the technological superiority of our Naval forces. Naval leadership has expressed a desire for and commitment to developing an innovative workforce. A prerequisite for innovation is relevant expertise. Widespread design expertise is one of the best strategies for the desired design innovation to occur at a high rate in an engineering workforce. Design decisions are known to be the most influential in determining the cost of a project and technological superiority of a weapons system. The bottom line for a case supporting the need for design engineer training is that training Naval engineers to be good design engineers is the path to achieving both an innovative workforce and affordable mission effectiveness.

### **Affordable Design Engineer training –Naval Design case based simulations concept**

It should be stated first and foremost that the best training for design engineering is actual practice under the guidance and direction of senior design engineers. Mentoring is part of the process, but not a substitute for training or performing the work through direct practice. The concept being proposed here is a structured training supplement to improve the design engineering skill set for those government engineers unable to get sufficient design practice opportunities to develop the desired level of expertise.

As McKesson points out, developing expertise and skills are a requirement for innovation, so clearly it should be a priority task. For any solution, the knowledge associated with design techniques, histories and methods needs to be captured in some communications form that is archiveable and retrievable, such as drawings, calculation sets, and serialized technical data products. Although there is a trend to move towards the paperless office in the government, electronic successors to the hard copies of past studies, lessons learned, drawings, revisions and calculation packages need to be proven effective in communicating to the next generation before hard copies are totally abandoned. Without this information, there are no lessons learned and similar corporate knowledge to be shared forwarded to subsequent generations of design engineers. They will be more or less doomed to repeat many of the mistakes of a prior generation relative to Naval equipment and systems, just using newer and more advanced tools. One noted expert identifies several skill sets necessary to achieve competency, the first being a heuristic and practice based competency, where the designer develops the ability to use and understand design precedents, principles, heuristics, and similar information as baseline assumptions and guidelines (Eder and Hosnedl 2008). Without this type of information, even motivated learners have very little to draw from to create or even determine which technically acceptable alternative is the best solution to the needs of tomorrow's missions. Knowledge management will be the cornerstone to any successful design engineering training structure and "accelerating knowledge transfer" is one of the tenets of the NAVSEA workforce excellence and judiciousness pillar. Prior publications have proposed a DAU style system (Galway 2010), a Knowledge Warehouse and associated Decision Support system (McKesson, The Application of Knowledge Management in Early-Stage Warship Design 2012), and Community of Practice (McKesson 2012). Part of the management of the knowledge involves assessments by current technical authority experts which information should be captured and put forward for future design engineers. This is problematic as there is a constant struggle for resources, time and attention in technical roles that must both support immediate fleet needs and ensure a quality technical training program for future engineers. The fleet always takes priority. Once identified, then a method of efficient and effective communication of this knowledge becomes the next hurdle. This involves some sort of training method that has easy access, easy maintainability, and little or no cost. Although the cost question can be debated, the solution almost has to be some form of e-learning experience. Perhaps here is an opportunity for a new type of on-line course experience that engages the student's curiosity and desire for enhancing creativity.

Prior works have suggested an on-line engineer training program for Naval Engineers similar to what DAU provides for the engineering management discipline of systems engineering (Galway 2010). While this concept offers many features for knowledge management, community of interest gathering, and general resource awareness, at the more advanced levels of design engineering, skills are developed more by mentored practice and applied techniques than general knowledge training. Since the opportunities to practice are diminishing in the government, an idea that follows the on-line concept is a dedicated series of progressive design engineering training simulations that are self-paced and peer reviewed.

In this scenario, a series of design problems in various technical disciplines within the Navy would be posted on line as problem statements. These problems would be similar to problems a senior engineering student might see in school, but related to specific systems, equipment, and processes found on current and future Naval Platforms. The progression of problems would start off re-enforcing basic Naval principles, practices, and procedures as applied to a particular discipline (structures, machinery, piping,

deck gear, electrical, electronic, propulsion, etc.). Problems would progressively get more difficult, leading to systems design, integration with existing equipment, and system-of-systems integration. There would be a tiered system of progression (Level I, Level II, Level III) where design engineers in levels II & III were also required to review the work done by the preceding level. All problems would carry the design from requirements to instructions for producing and testing a component, system, or process. There would need to be a cost estimate done for the work (given rates and production process estimating values). There would need to be a sketch or drawing done for each problem. There would need to be an engineering data package developed that justified design engineering decisions made in terms of cost, risk, and function. These problems might take about a week to complete over a period of say 30-60 days. Once completed, these packages would be submitted to a centralized location and reviewed by peers. There would be no names, specific ship references, or real in-service performance information used as reference to avoid controversy. Once received, the design engineering training supervisor would review the package and then assign the package to a level II design engineer for peer review. The review would be anonymous and it would be again submitted back to an engineering training supervisor for evaluation and the student as a critique. In addition to the peer review responsibilities, the Level II design engineering student would have a series of more complex problems to solve. The Level III design engineers would similarly be asked to review the problems done by the Level II design engineers, as well as comment on their reviews of the Level I students work. Level III students would be given more advanced problems and once again submit them to the training supervisor for review, as well as other work. This time however, the peer reviews would be done by other Level III students, Level III graduates for continuing education credits, and by other people in the Technical Authority line that were interested in seeing the level of work being done by students. Level III students and graduates would be expected to also submit problems from the field that were good learning examples for the Level I & Level II students. Problems for level III students (and other levels as well) would be submitted by and vetted through Technical Authorities such as Technical Warrant Holders, Ship Design Managers, and Engineering Leadership within the Navy.

The current situation of the Naval government technical workforce calls for DoD to once again make a bold and decisive corrective action to re-balance the acquisition support vs technical excellence scales in the area of training and workforce development, thus keeping the intent of Secretary Perry's original acquisition reform plan on course. The system for design engineering training suggested by this paper would be relevant, flexible, and lead to things like technical mentorship, knowledge management, instilling sound design decision making processes and design engineering resource awareness. However, there would be a price. There would be an administrative program to track and maintain the system. There would be a burden on all technical authorities to contribute to the program to make sure it was on target with the needs of the Navy. The human resource return would be in the form of confidence in the design capabilities of support members in a Technical Warrant Holder's support pyramid. There would need to be time allotted by the Supervisors for this training requirement. There would need to be a DoD level commitment to training the technical community that was equal to the commitment to DAWIA training. If this meant changing laws or changing policy to adjust periods of accomplishment for both certifications to be reflective of available training time and resources, then that would be the action from the commitment. These are not trivial training program actions. However, the result would be a workforce with a progressive path within the government to provide the level of subject matter expertise and understanding that would increase the probability of relevant technical innovation. Without some sort of

technical educational structure that enables the body of design engineering knowledge associated with today's navy to be passed to tomorrow's design engineers such as is described here, the Navy is relying on random chance and divine inspiration to achieve its innovative goals.

The motivation for the participant in the program would need some consideration as well. There would need to be some financial or career enhancing enticement to motivate all engineers to take this training. However, many would take it as a means to build career expertise. If the credential of a Level I, II, or III Design Engineer could gain the prestige and cross-department acceptance of a DAWIA certification, then there may be sufficient motivation for many to take the training just for career advancement. If word spreads that the training is worthwhile, it may become popular and even competitive and fun. If we achieve a training program that an engineer wants to take, we might be able to successfully counteract the effect from lost actual design and production experience. Financial incentives are hard to come by in this economic environment, but as the skill levels increase and become recognized, perhaps awards could be considered. One thought is to tie career ladder promotions to achieving the next level. Another thought is to tie engineering college tuition support to a commitment to achieve a certain competency level in Naval Engineering design. Until such a time, some sort of incentive such as a series of challenge coins might be incentive enough. Like in Scouts, just providing a way to incrementally develop into a better engineer should be incentive enough for the highly motivated.

## **CONCLUSIONS**

- 1) Providing a method of transferring the existing body of Naval corporate technical knowledge relative to equipment, systems and procedures in the field today is essential in the continuation of fielding technically superior naval equipment and systems. In the case of knowledge, this means capturing, archiving, and providing access to the engineering data needed to build new solutions on the strength of prior work. In the case of a design engineering workforce, it means providing a structured training program that is resourced, supported by DoD and maintained with the vigilance and energy that the DAU put into the Acquisition workforce. The acquisition workforce and the technical workforce, specifically design engineering workforce, are coupled and dependent on each other for success.
- 2) The seeds of innovation need to be planted by selecting well balanced and creative design engineers, then developing relevant expertise and skills. Once the relevant expertise is developed, individual creativity and opportunity for innovation will all need to align to potentially yield results. The key is developing an innovative workforce, not just hoping for one, trying to buy one or trying to create process that logically leads to innovation. Give them tools, build their expertise, create pathways for shared knowledge and provide opportunity. The rest will happen if the environment is right.
- 3) NAVSEA's mission priority of Technical Excellence and Judiciousness is looking for innovative ways to accelerate transfer of knowledge to those coming into jobs now and in the future. DoD has stated that :

“DoD cannot be an effective customer for technical excellence and innovation if we do not embody those characteristics fully in our own workforce. We cannot make decisions about technology if we don’t fully understand what is possible and how to achieve it.”  
(Frank Kendall, OSD AT&L 2014).

DoD is looking for ways to define and implement methods to capture, organize, access and share key pieces of information within and across competency domains, and to connect employees at different skill and experience levels that need similar knowledge. The on-line methods described by Galway (Galway, On-Line Naval Engineering skills supplemental training Program 2010) and herein are one path to possibly achieving this objective.

- 4) If we are to continue our long-term goals of naval war fighting superiority, then the talk of having an innovative workforce needs to be followed by actions that lead to developing, monitoring, and managing the government’s naval design engineering human resource. This paper provides a case for supporting these actions towards development of a program to accomplish these goals and maintaining continuity in the naval design engineering workforce.

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## Appendix A-Key Terms

*Systems engineering* (Defense Acquisition University 2013):

- Systems engineering (SE) is a methodical and disciplined approach for the specification, design, development, realization, technical management, operations, and retirement of a system.
- Systems engineering (SE) establishes the technical framework for delivering materiel capabilities to the war fighter.
- SE provides the foundation upon which everything else is built and supports program success.
- SE ensures the effective development and delivery of capability through the implementation of a balanced approach with respect to cost, schedule, performance, and risk using integrated, disciplined, and consistent SE activities and processes regardless of when a program enters the acquisition life cycle.
- SE also enables the development of engineered resilient systems that are trusted, assured, and easily modified (agile).
- SE planning, as documented in the Systems Engineering Plan (SEP), identifies the most effective and efficient path to deliver a capability, from identifying user needs and concepts through delivery and sustainment.
- SE event-driven technical reviews and audits assess program maturity and determine the status of the technical risks associated with cost, schedule, and performance goals.

Relevance: The relevance of the systems engineering definition is that systems engineering has become an umbrella for the entire acquisition technical process, including design, to both practitioners and on-lookers alike. Providing the technical training necessary to gain expertise in an area of such scope is problematic. An interesting observation is that a systems engineering perspective is more of a “top down” concept for complex systems, focusing on optimizing system interrelationships relative to over-arching performance. On a complex system such as a ship, it is unlikely that a systems engineer would be directly responsible for all the systems. DAU’s definition of Systems engineering also includes many non-technical engineering management items. The current civilian engineering workforce is with increasing frequency taking systems engineering view of problems rather than a traditional design engineering view. The current civilian workforce is being trained to handle the increased breadth of responsibilities associated with acquisition support systems engineering at the expense of training to increase the depth of understanding about today’s equipment, systems and processes. The balance between the acquisition community and the technical community has been the subject of prior publications (Galway 2013). However, successful acquisition support systems engineering often demands an advanced understanding of design and production knowledge.

### *Engineering Design and Design Engineer*

“Engineering design is the systematic, intelligent generation and evaluation of specification for artifacts whose form and function achieve stated objectives and satisfy specified constraints.” (Brown 2012) For purposes of this effort, an engineer in any discipline primarily performing engineering design functions as a design engineer. A Naval design engineer supports acquisition by providing technically acceptable alternatives for the technical authority by applying knowledge, skills, experience and judicious decision

making to the tasks of problem solving and realistic transfer of requirements into integrated systems or stand-alone artifacts.

**Relevance:** The relevance of the engineering design and design engineer definitions are to clarify the group of interest in this paper. The focus of this effort is on transitioning new degreed engineers into engineers that have acquired naval system knowledge and can successfully apply their engineering skills in the design and production of Naval Systems. The paper will refer to this group commonly as Naval design engineers. The paper also uses NAVSEA as a SYSCOM example where design engineers are needed, but the discussion has relevance to other SYSCOMs within the Navy, and potentially other technical groups within DoD involved in balancing acquisition training with relevant technical training for an engineering workforce. A design engineering perspective is “bottom up”, focusing on delivering a prescribed set of components, equipment, or systems that meet functional requirements and successfully integrate with the rest of the equipment in a larger complex system, as defined by constraints, prior heuristics, and production foresight. On a complex system like a ship, it is quite likely that a design engineer would be responsible for all aspects of one system or sub-system, including successful integration and installation with other systems and sub-systems. Design engineering typically requires more depth of understanding in one area than systems engineering. It should also be noted that although the term Naval Engineer applies to all age groups, the group targeted by this effort is the more junior engineers in the 2-10 years of service. This period on Naval Engineer development spectrum is just after new employee indoctrination, but before becoming a journeyman design engineer. The assertion here is that during this period the greatest amount of relevant job knowledge transfer will occur, and subsequently this group would benefit the most from a structured skills training and knowledge management programs. It is also noted here that anyone can design. It further assumed that their success will be at least partially proportional to their relevant knowledge and training, but there are many other individual influences. In many production situations, there is also a technical role for a ‘Designer’. This role describes a person who has relevant design expertise gained by working their way up through the production process or having completed a specific design apprenticeship. However within the government, this role seems to be transitioning to degreed engineers who have no OJT design experience. The e-learning style training methods for design engineering presented in this paper would benefit all practitioners through the life cycle of a design engineering career.

***Naval Engineering*** (American Society of Naval Engineers(ASNE) 2012)

Naval Engineering as that branch of engineering that includes related arts, sciences and use of technology in the design, systems integration, interoperability, construction, operation, maintenance, logistics support, inactivation and disposal of:

- Warfare systems including command and control, electronics, and ordnance systems, aviation and space systems, surface and sub-surface ships, marine craft, and maritime auxiliaries,
- Ocean structures and associated shore facilities that are used by the naval or other military forces and civilian maritime organizations for the defense and well-being of the nation.

Naval engineering combines traditional naval architecture and marine engineering with other engineering disciplines such as:

- C4ISR (Command, Control, Communications, Computers, Intelligence, Surveillance & Reconnaissance)
- Environmental Engineering
- Modeling and Simulation
- Total Systems Engineering (including the use of commercial components)
- Total Ownership Costs
- Information Technology

**Relevance:** The relevance of the Naval engineering definition is to show the breadth of material it encompasses in terms of disciplines, equipment and processes. Naval Engineering and Systems Engineering used together form a huge breadth of responsibilities. Naval Engineers functioning in the role of design engineers (Naval design engineers) need to be able to generate potentially successful design concepts to meet current and future customers' needs, develop them until the artifact represents a good balance of affordable mission operational effectiveness, and then produce them such that they will not fail during a mission for the life-cycle of the equipment or system.

### ***Mentoring***

Mentoring is an effective way to provide professional development and enhance learning in the workplace. The mentoring relationship is a special relationship built on trust, encouragement and targeted development. A mentor is a teacher, coach, and advisor who provide guidance and opportunities for learning and professional growth to another (Carderock 2013). Mentoring should not be thought of as training, coaching, or teaching. These are short term in general and focused on specific items and goals. Mentoring is more of a long term relationship, often a friendship that benefits both parties. (Ann Marie Dinkel 2011)

**Relevance:** The relevance of the mentoring definition is to distinguish it from formal training. Formal training is being suggested by this paper as mitigation for the risk accepted by DoD associated with the acquisition reform decision and variance between design engineering skills needed and design engineering resources available. Mentoring can be formal or informal. Formal mentoring involves the pairing of a younger person with a more senior person that provides a conduit for helping guide the junior engineer on a proven path of success within an organization. Informal mentoring might include informal design discussions and guidance from senior design personnel in the way of reviewing work, helping with prior known good design techniques or vendors, and possibly helping with the design corporate knowledge transfer through experience. Quite often, mentoring is an unfunded professional goodwill venture on the part of the senior personnel as they are interested in ensuring the success of the next generation. Mentoring is a dividend of a healthy team environment, but is informal and should not be burdened with the formal transfer of the body of knowledge associated with the equipment, systems and processes of today's Navy. Mentoring might be better thought of as a way to help make the transfer process more efficient and effective. There is a trend in DoD to answer unfunded training issues with the concept of mentoring. Mentoring has its place, but it is not training.

## **Appendix B –Acquisition Reform related impacts to Government Internal Design and Production Engineering Capabilities**

<b>Change</b>	<b>Impact to Engineering Workforce</b>
Reduction in production facilities	Lost opportunity to practice design and production skills
Reduction in design workforce	Tendency to merge roles of draftsman/designer/engineer, more tasks for remaining workers causing management of design work rather than actual practice
Reduction in purchased or created engineering data	Poor documentation of design history, lost lessons learned, re-work of design for modifications, increase in technical risk accepted
Focus on training acquisition support systems engineers	Increased breadth of responsibilities and less depth of understanding, more engineering management responsibilities less technical responsibilities
Increased workforce churn/personnel turn-over/reorganization	Loss in useful corporate technical knowledge, design history and skills
Virtual work spaces	Loss in inter-office communication and direct mentoring opportunities
Increase in complexity of components, systems and equipment, including mechatronic and computer controlled equipment	Greater amount of time required to understand and master design skill set, high rate of obsolescence, greater dependence of IT skills and communication, deeper integration requirements, proprietary information issues
Greater software security requirements and more complex engineering software tools	More training time to gain expertise, software compatibility issue with government networks, loss in skill set relevance with job transfers
Internet	More choices for design decisions, more alternatives for Analysis of Alternatives
Lack of design engineering career path advancement	Lack of career advancement motivation to stay in equipment, system or process design roles, relative to management, research or systems engineering
Attrition of senior design engineers	Loss in mentors, loss in ability to transfer lessons learned, loss of undocumented design histories
Funding pressures for engineering workforce technical training	Overhead training budgets have been reduced to near zero for technical training and Navy labs have limited or no opportunity to pay for development training directly from the Navy Working Capital Fund. (Government Accounting Office 2007)
Increased fiscal pressures on program authority and reduced technical authority influence.	Design engineering value is not being represented, increased designing to fix poor initial acquisition choices. Less government control and oversight in design decision making

## Appendix C - Core Attributes of Design Thinking

Attribute	Explanation	Design Relevance
Ambiguity	Being comfortable when things are unclear or when you do not know the answer	Design thinking addresses ill-defined and wicked problems
Collaborative	Working together across disciplines	People design in interdisciplinary teams
Constructive	Creating new ideas based on old ideas, which can also be the most successful ideas	Design Thinking is a solution-based approach that looks for an improved future result
Curiosity	Being interested in things you do not understand or perceiving things with fresh eyes	Considerable time and effort is spent on clarifying the requirements. A large part of the problem solving activity, then consists of problem definition and problem shaping.
Empathy	Seeing and understanding things from your customers' point of view	The focus in user needs (problem context)
Holistic	Looking at the bigger context for the customer	Design thinking attempts to meet user needs and also drive business success
Iterative	A cyclical process where improvements are made to solution or idea regardless of the phase	The Design Thinking process is typically non-sequential and may include feedback loops and cycles
Non - Judgmental	Creating ideas with no judgment toward the idea creator or the idea	Particularly in the brainstorming phase, there are no early judgments
Open Mindset	Embracing design thinking is an approach for any problem regardless of industry or scope	The method encourages "outside the box thinking" (wild ideas); it defies the obvious and embraces a more experimental approach.

*Table is directly From Curedale (Curedale 2013) but author of paper added heading for clarity*